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AIRFLOW DISTRIBUTION CONTROL SYSTEM FOR USAGE IN A RAISED-FLOOR DATA CENTER

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BACKGROUND OF THE INVENTION

[0001] Electronic systems and equipment such as computer systems, network interfaces, storage systems, and telecommunications equipment are commonly cooled using a pressurized under-floor plenum. Hot air exhausted by electrical equipment in a data center room is drawn into Computer-Room Air Conditioning (CRAC) units via powerful fans in the CRAC units. The CRAC fans cool the hot air by forcing the air through a liquid-to-air heat exchanger. Pressurized cooling air then enters a plenum beneath the data center floor. Cooled air is distributed to the equipment in the room by placing floor tiles with perforations in close proximity to the cool air inlet vents of the equipment.

[0002] Typically, during final stages of a data center upgrade or new construction, airflow through the perforated tiles is measured to plan for sufficient cooling to meet expected room equipment heat loads. Adjustments are made to the quantity and placement of the perforated tiles and CRAC blower speed is to set a desired air flow rate. Control of changes in flow rate is difficult to achieve once deployment is complete. However, unintentional changes to flow rate are common. Over time, flow rates generally decrease due to addition of cables and other obstructions in the plenum. Holes in the plenum are often created for cable routing and can cause drastic changes to initial tile flow rates by creating low-resistance bypass for the high-pressure cooling air. Therefore, attaining a planned airflow distribution in the data center is difficult due to the complex nature of airflow and pressure distribution in the plenum.

[0003] Air exits from the CRAC at a very high velocity. At a distance from the CRAC units, air velocities are low and uniform. The combination of conditions often results in a non-intuitive and undesirable airflow distribution through the perforated tiles. Airflow is low or negative, drawing air from the data center into the plenum, near the CRAC unit. In contrast, airflow is higher distal from the CRAC unit.

SUMMARY

[0004] What are desired are a system and method that enable dynamic control of airflow in a raised-floor data center.

[0005] In accordance with various embodiments exemplified herein, an airflow distribution control system for usage in a raised-floor data center comprises an under-floor partition with a controllable flow resistance and a sensor. The partition is capable of selective positioning in a plenum beneath the raised-floor. The sensor is communicatively coupled to the partition and detects a parameter indicative of airflow distribution and controls the flow resistance based on the parameter.

[0006] According to other embodiments, an airflow control apparatus for usage in a raised-floor data center comprises a partition configured for under-floor installation, a plurality of adjustable apertures in the partition, and a servomotor. The servomotor is coupled to the apertures and can control flow resistance of the partition.

[0007] In accordance with additional embodiments, a ventilation system for a data center comprises a raised floor overlying a plenum space, at least one under-floor partition with a controllable flow resistance, and at least one sensor. The raised floor further comprises a plurality of tiles. The partitions are selectively positioned in the plenum beneath the raised-floor. The sensors are communicatively coupled to one or more partitions and detect a parameter indicative of airflow distribution and control flow resistance based on the parameter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Embodiments of the invention relating to both structure and method of operation, may best be understood by referring to the following description and accompanying drawings.

[0009] **FIGURE 1** is a simplified schematic pictorial diagram illustrating a cut-away view of an embodiment of an airflow distribution control system for usage in a raised-floor data center.

[0010] **FIGURE 2** is a simplified schematic pictorial diagram showing a cut-away view of another embodiment of an airflow distribution control system that includes a plurality of under-floor partitions.

[0011] **FIGUREs 3A**, **3B**, and **3C** are simplified schematic pictorial diagrams depicting cut-away views of some embodiments of an airflow distribution control system that include multiple under-floor partitions.

[0012] **FIGURE 4** is a schematic pictorial diagram illustrating an embodiment of an airflow control apparatus for usage in a raised-floor data center.

[0013] **FIGURE 5** is a perspective pictorial diagram illustrates an embodiment of a ventilation system that can be used in a data center.

DETAILED DESCRIPTION

[0014] Various aspects of a ventilation system operate to control airflow distribution in a raised-floor data center by sensing a parameter indicative of airflow distribution and adjusting flow resistance distribution in a plenum under the raised floor based on the sensed parameter.

[0015] The ventilation system can implement airflow control either autonomously or manually and can adjust to conditions to supply cooling directly to a thermal source.

[0016] Referring to **FIGURE 1**, a simplified schematic pictorial diagram illustrates a cut-away view of an embodiment of an airflow distribution control system **100** for usage in a raised-floor data center **102**. The system **100** comprises an under-floor partition **104** with a controllable flow resistance **106**. The airflow distribution control system **100** also comprises a sensor **108**. The partition **104** can be selectively positioned in a plenum **110** beneath the raised-floor **112**. The sensor **108** is communicatively coupled to the partition **104** and detects a parameter indicative of airflow distribution. The sensor **108** controls the flow resistance based on the parameter.

[0017] The sensor **108** can be any type of suitable air flow sensor or transducer, for example including airflow sensors, pressure sensors, and temperature sensors. In some embodiments, one or more of various transducer types can be used as sensors to detect parameters usable for controlling and modifying airflow distribution in the data center **102**. Appropriate control parameters include air flow characteristics, pressure, temperature, and the like.

[0018] Some configurations can use an array of thermometers as the sensor **108**, for example distributing the thermometers throughout the data center room **102**. In various arrangements, one or more sensors **108** can be located in any appropriate location in the plenum **110** below the raised-floor and/or located in a suitable location above the floor in the data center room. In a particular example, a system **100** may include a sensor **108** located below each tile of the raised floor that is capable of measuring velocity and temperature. Walls or partitions **104** in the floor plenum **110** can be adjusted based on

feedback from the sensors **108**. Sensors **108** can otherwise be located in an electronics rack or in electronic equipment.

[0019] In other embodiments, the sensor **108** can be an air flow transducer of the type used for control, surveillance, and regulation of flow rate in fresh-air and ventilation systems. In a particular embodiment, an air flow transducer may register airflow speed according to the thermal principle that cooling action of air increases with airspeed. An airflow transducer can include temperature-dependent resistors manufactured using thin-film technology that creates radiant heat in the resistor substrate. Air flowing past the resistor shifts the radiant heat and creates a differential voltage at the resistors, which are connected to form a bridge. Electrical signals generated by the transducer indicate air flow and direction.

[0020] In the illustrative system **100**, the controllable flow resistance **106** is shown as a plurality of adjustable apertures in the under-floor partition **104**. A servomotor **114** is coupled to the apertures **106** and communicatively coupled to the sensor **108**. The servomotor **114** responds to communication from the sensor **108** to open and close the apertures **106**, thereby controlling flow resistance of the partition **104**.

[0021] Referring to **FIGURE 2**, a simplified schematic pictorial diagram illustrates a cut-away view of another embodiment of an airflow distribution control system **200** that includes a plurality of under-floor partitions **202, 204** with controllable flow resistances **206**. The partitions **202, 204** are selectively positioned in the plenum **210** under the floor **212** and are independently controllable by the sensor **208**. In the illustrative embodiment, the various under-floor partitions **202, 204** have adjustable apertures **206** of varying sizes and densities to function as controllable air flow resistances.

[0022] In the particular example, the apertures **206** are configured as a plurality of louvered shutters in the under-floor partitions **202, 204**. A servomotor **214** is coupled to the louvered shutters **206** and in communication with the sensor **208**. The servomotor **214** responds to communication from the sensor **208** to control flow resistance of the partitions **202, 204**.

[0023] The airflow distribution control system **200** enables autonomous and/or manual control of air flow distribution in a raised-floor data center by adding vertical or otherwise arranged partitions **202, 204** with controllable flow resistances **206** to the under-floor plenum **210**. The sensor **208** measures a parameter indicative of airflow distribution in the room. The sensed parameter is used to balance air flow distribution to match thermal loads imposed by data center equipment. In some arrangements or in some conditions, the sensed parameter is applied to a controller that activates an automatic response. Alternatively, the sensed parameter can be displayed, enabling manual control of the controllable airflow resistances **206**.

[0024] Conditions in the data center vary over time and the airflow distribution control system **200** responds to the variations in thermal loads to accommodate variations in environmental conditions, addition or removal of equipment, adapt for intrusions into the plenum such as drilling of holes in the floor or insertion of cables into the plenum **210**.

[0025] An air conditioning system injects air into the plenum **210**, generating a pressure distribution under the floor **212**. The partitions **202, 204** with controllable airflow resistances **206** modify the pressure and airflow distribution in the plenum **210**, thereby controlling the distribution above the floor **212** to adapt to conditions in the data center.

[0026] Referring to **FIGURE 3A**, a simplified schematic pictorial diagram illustrates a cut-away view of an embodiment of an airflow distribution control system **300** that includes a plurality of under-floor partitions **302, 304**, each with controllable flow resistances **306** to create a converging channel with an area that decreases from the center-line of the data center room **314**. The partitions **302, 304** are selectively positioned in the plenum **310**. A network of distributed sensors **308** is arranged in the data center room **314** and is communicatively coupled to the plurality of under-floor partitions **302, 304**. The sensor network **308** can control the air flow resistance of the partitions **302, 304** independently. For example, in some embodiments and/or in some circumstances or conditions, the flow resistance of one partition **302** may be controlled independently of

the other partition **304**. In other embodiments and/or circumstances or conditions, the various flow resistances **306** can be controlled independently of one another.

[0027] **FIGURE 3B** illustrates an embodiment of an airflow distribution control system **300** with under-floor partitions **302** and **304** that extend in a line across the data center **314** and divide the room into three sections. The impingement of flow on the partitions **302, 304** produces higher pressures on the upstream side with respect to the air conditioning source, and produces a reduction in pressure across the partitions **302, 304**. In the illustrative system **300** the apertures forming the flow resistance **306** are arranged to be larger for the partition **304** more distant from the air source.

[0028] **FIGURE 3C** illustrates an embodiment of an airflow distribution control system **300** with under-floor partitions **302, 304, 305** that extend in across the data center **314** in radial arcs centered at the air conditioner and divide the room into four sections.

[0029] The partitions can extend into the plenum **310** at various angles. In some cases the partitions can be vertical or any angle from horizontal to obtain a desired effect on air flow. Multiple partitions can be arranged in any suitable geometry under the floor **312** to obtain a desired pressure and air flow movement profile. In some examples, the partitions can be arranged to intersect in a grid configuration. In other examples, the partitions can be aligned in parallel. Partitions can be arranged according to a planned or expected floor plan configuration of equipment above the floor.

[0030] In a particular embodiment, the grid concept can be extensible to include a two foot by two foot flooring arrangement in which 2x2 floor tiles are distributed over vertical walls aligned at edges of the tiles.

[0031] Referring to **FIGURE 4**, a schematic pictorial diagram illustrates an embodiment of an airflow control apparatus **400** for usage in a raised-floor data center. The airflow control apparatus **400** comprises a partition **402** configured for under-floor installation, a plurality of adjustable apertures **404** in the partition **402**, and a servomotor **406**. The servomotor **406** is coupled to the apertures **404** and adjusts positioning of

deflecting blades **408** that cover the apertures **404**, thereby controlling flow resistance of the partition **402**.

[0032] The illustrative airflow control apparatus **400** includes a plurality of louvered shutters in the partition **402**. In some embodiments, a partition **402** can have a plurality of adjustable apertures **404** of varying sizes and densities. Some partitions may have multiple server motors **406** so that different portions of the partition **402** can be managed to have different flow resistance concurrently.

[0033] Referring to **FIGURE 5**, a perspective pictorial diagram illustrates an embodiment of a ventilation system **500** that can be used in a data center **502**. The ventilation system **500** comprises a raised floor **504** overlying a plenum space **506** and one or more under-floor partitions **508** with controllable flow resistance **510**. One or more sensors **512** are distributed in selected locations in the data center **502**. The raised floor **504** further comprises a plurality of tiles **514**. The partitions **508** are selectively positioned in the plenum **506** beneath the raised floor **504**. The sensors **512** are communicatively coupled to one or more partitions **508** and detect a parameter indicative of airflow distribution. A controller **516** receives signals from the sensors **512** and controls flow resistance based on the parameter.

[0034] The raised-floor tiles **514** include solid tiles **518** and perforated tiles **520** that are selectively arranged to manage airflow from the plenum space **506** to the data center **502** above the raised floor **504**.

[0035] The ventilation system **500** further comprises at least one air conditioning unit **522** that is arranged to inject cooling air into the plenum **506**. In some embodiments, the ventilation system **500** includes multiple under-floor partitions **508** arranged in a series so that partitions **524** with higher flow resistance are positioned generally more proximal to the air conditioning unit **522** and partitions **526** with lower flow resistance are positioned generally more distal to the air conditioning unit. Because air velocity is at a maximum near the CRAC, pressure is at a minimum. As velocities decrease, pressure increases. The walls are intended to increase pressure near the CRAC. Higher flow resistance walls are located near the CRAC.

[0036] The arrangement of resistances is highly variable depending on the particular environment. Some room configurations may indicate an opposite arrangement, for example if all information technology (IT) equipment is near the CRAC. However, generally uniform velocities are desired in the under floor plenum.

[0037] In an illustrative embodiment, the multiple under-floor partitions **508** can be arranged in a selected pattern in which individual partitions have flow resistance that is controllable independently of other partitions. The under-floor partitions **508** can have adjustable apertures of varying sizes and densities.

[0038] The sensors **512** are selectively distributed in the data center **502** and a process executable in the controller **516** takes into account the spatial sensor distribution to determine a spatial distribution of the parameter indicative of airflow distribution. Based on the airflow distribution signals from one or more of the sensors, the controller generates control signals to adjust flow resistance among the plurality of partitions **518**. The controller **516** can control specific partitions or sections of partitions independently based on the parameter spatial distribution.

[0039] The controller **516** adjusts flow resistance among the multiple under-floor partitions **508** by adjusting apertures of varying sizes and densities..

[0040] The controller **516** receives signals from the sensors **512** and processes the received signals to determine flow resistance settings for the partitions **508** that are suitable for controlling air flow in the data center **502**. In an illustrative embodiment, the flow resistance control device **510** is a plurality of adjustable apertures **510** in the under-floor partition **508**. For example, a servomotor can be coupled to the apertures **510** to set the aperture size based on commands received from the controller **516**. Controller commands are determined based on signals received by the controller **516** from the sensors **512**. The controller **516** executes a process that tracks sensor information over time and determines appropriate flow resistance settings to control flow resistance in the data center **502**.

[0041] In a particular embodiment, the flow resistance **510** can be multiple louvered shutters in one or more of the under-floor partition **508** with a servo motor coupled to the louvered shutters. The controller **516** can execute a process that tracks sensor data over time and generates servo motor commands to manage positioning of dampers or blades in the louvered shutters to control flow resistance.

[0042] The sensors **512** are arranged in a network and send signals to the controller **516** including information relating to a parameter indicative of air flow and information enabling the controller **516** to determine the position of the measurement in the data center **502**. Spatial information acquired by the network of distributed sensors **512** are communicated to the controller **516**, which processes the information and determines settings for controlling flow resistance in the plenum **506**. Flow resistance may be controlled independently for individual partitions and for particular segments of partitions.

[0043] The sensors **512** can be distributed in computers, system racks, and in other strategic locations in the data center **502** as appropriate to supply airflow condition signals for controlling the airflow resistance in the plenum **506**.

[0044] Various types of sensors **512** can be used for a particular ventilation system **500** such as sensors, pressure sensors, temperature sensors, and the like. In a particular ventilation system **500** the network of sensors **512** can include uniform sensors of all one type, or can include a mixture of particular sensors and sensor types.

[0045] The illustrative ventilation system **500** operates to control airflow distribution in the data center **502** holding various electronic equipment **528**. The data center **502** has a hot aisle-cold aisle arrangement with the air conditioning unit **522** and the perforated tiles **520** in the cold aisles. Equipment **528** such as computer servers are arranged on two sides of the cold aisles with air intake sides facing the cold aisles. The air exhaust exits of the equipment **528** face hot aisles. The air conditioning unit **522** injects cooling air into the plenum **506**, which exits the perforated tiles **520** and is pulled into the equipment **528** by fans internal to the equipment. The equipment **528** heats the cooled air during

operations and exhausts the hot air rearward into the hot aisles. The heated exhaust returns to inlets of the air conditioning unit **522**.

[0046] The controller **516** can dynamically respond to conditions measured by the sensors **512** to control airflow. For example, the controller **516** can adjust the flow resistance **510** in particular partitions **508** and/or or particular sections of the partitions **508**. The controller **516** adjusts flow resistance among the plurality of partitions **508** independently based on the sensed parameter or parameters. In general, the controller **516** can open partition apertures to lower resistance in a particular location to cause additional airflow to a region and, conversely, can close apertures to reduce local airflow.

[0047] Implementation of partitions **508** with controllable flow resistances **510** to the plenum **506** enables increased flexibility in attaining desired flow rates through the perforated floor tiles **520**.

[0048] The dynamic capabilities of the ventilation system **500** enable adjustment to large variations in thermal conditions resulting from presence of service or construction personnel in the data center **502**, addition or removal or equipment units, changes occurring during construction of the data center **502**.

[0049] Usage of the distributed sensors **512** enables the controller **516** to respond dynamically to changes in local conditions in specific locations in the data center **502**, for example to increase airflow in the vicinity of a particular equipment unit in response to increased heat production by the unit. Similarly, the controller **516** can decrease airflow to a region when a particular equipment unit is turned off or removed. The ventilation system **500** permits flexible changes in airflow in response to changes in data center environment caused by equipment changes or failure of system-level cooling or computer-room air conditioning units. The under-floor partitions **508** can be controlled in response to an air conditioning unit failure by using a feedback loop from the sensors **512** to the control the adjustable resistance **510** to close flow to isolate the failed unit. Resistance adjustments may be made manually or by servo motor control based on feedback of parameters such as temperature, airflow, and/or pressure. For example, temperature data may be accessed from temperature feedback from information

technology systems, room temperatures, or computer-room air conditioning air temperatures, either supply or return.

[0050] The ventilation system **500** enables cooling air to be used effectively in an underutilized data center. Often, a fraction of the floor space of a new data center is filled with equipment since enterprises typically begin operations with excess capacity to allow for growth. Given the large capital costs associated with data center construction, the housed building is constructed to accommodate further information technology expansion of system criteria. In general operation, the entire under-floor plenum is pressurized, regardless of floor usage. Often computer-room air conditioning units are operated to properly pressurize the plenum to deliver an appropriate amount of cooling air to the room equipment. The partitions **508** with adjustable resistances **510** can be installed during a construction phase, permitting the plenum **506** to be subdivided based on floor utilization. Computer room air conditioning units can be installed during a construction phase, enabling the plenum to be sub-divided based on floor utilization. Resources can be conserved by waiting to activate a computer room air conditioning unit until the previously activated units can no longer supply sufficient cooling.

[0051] The partitions **508** with adjustable resistances **510** can also be used to prevent or avoid loss of cooling airflow caused by intrusions, for example insertion of bulky items or cables, into the pressurized plenum. Control of airflow is also useful in response to changes in pressure, and thus disturbances in airflow, caused by removal of tiles from the data center floor during maintenance or by improper installation of a floor grid, creating a low-pressure by-pass of cooling air. Disturbances in airflow can result in insufficient receipt of cooling air in other parts of the data center, potentially causing system failure.

[0052] The ventilation system **500** system also enable isolation of failed computer room air conditioning units from the remainder of the plenum, preventing air bypass through the air conditioning unit. Cut-outs in the data center floor tiles are commonly used to route cabling from an equipment unit rack into the plenum, creating low-pressure bypasses. The adaptive ventilation system **500** can isolate floor areas containing cut-outs from the plenum using the partitions **508**. Resistances can be adjusted manually or through usage of a servo motor control process.

[0053] The various functions, processes, methods, and operations performed or executed by the system can be implemented as programs that are executable on various types of processors, controllers, central processing units, microprocessors, digital signal processors, state machines, programmable logic arrays, and the like. The programs can be stored on any computer-readable medium for use by or in connection with any computer-related system or method. A computer-readable medium is an electronic, magnetic, optical, or other physical device or means that can contain or store a computer program for use by or in connection with a computer-related system, method, process, or procedure. Programs can be embodied in a computer-readable medium for use by or in connection with an instruction execution system, device, component, element, or apparatus, such as a system based on a computer or processor, or other system that can fetch instructions from an instruction memory or storage of any appropriate type. A computer-readable medium can be any structure, device, component, product, or other means that can store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

[0054] The discussion depicts process acts that may represent modules, segments, or portions of code that include one or more executable instructions for implementing specific logical functions or steps in the process. Although the particular examples illustrate specific process steps or acts, many alternative implementations are possible and commonly made by simple design choice. Acts and steps may be executed in different order from the specific description herein, based on considerations of function, purpose, conformance to standard, legacy structure, and the like.

[0055] While the present disclosure describes various embodiments, these embodiments are to be understood as illustrative and do not limit the claim scope. Many variations, modifications, additions and improvements of the described embodiments are possible. For example, those having ordinary skill in the art will readily implement the steps necessary to provide the structures and methods disclosed herein, and will understand that the process parameters, materials, and dimensions are given by way of example only. The parameters, materials, and dimensions can be varied to achieve the desired structure as well as modifications, which are within the scope of the claims. Variations and modifications of the embodiments disclosed herein may also be made while remaining

within the scope of the following claims. For example, a few specific examples of partitions and devices for adjusting airflow resistance in the partitions are described. The illustrative techniques can be used with any suitable type, geometry, or configuration of partition and flow control devices. Automatic embodiments disclose usage of a servo motor to control positioning of blades or other covers of apertures in the partition. Any suitable type of motor and any appropriate resistance adjustment device may be used. Particular sensed parameters include airflow, pressure, and temperature. Any suitable parameter that is indicative of airflow, such as motion detectors and the like, may otherwise be used.